Estimation of Boreal Forest Biomass Using Spaceborne SAR Systems

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Abstract

In this paper, we report on the use of a semi-empirical algorithm derived from a two layer radar backscatter model for forest canopies. The model stratifies the forest canopy into crown and stem layers, separates the structural and biometric attributes of the canopy. The structural parameters are estimated by training the model with polarimetric SAR (synthetic aperture radar) data acquired over homogeneous stands with known above ground biomass. Given the structural parameters, the semi-empirical algorithm has four remaining parameters, crown biomass, stem biomass, surface soil moisture, and surface rms height that can be estimated by at least four independent SAR measurements. The algorithm has been used to generate biomass maps over the entire images acquired by JPL AIRSAR and SIR-C SAR systems. The semi-empirical algorithms are then modified to be used by single frequency radar systems such as ERS-1, JERS-1, and Radarsat. The accuracy of biomass estimation from single channel radars is compared with the case when the channels are used together in synergism or in a polarimetric system.

Introduction

There is an increasing interest in estimating forest biomass for both practical forestry issues and scientific purposes. Biomass estimates are critical for studying the ecosystem structure and function and provide the means for assessing the timber value, forest productivity, regeneration, decomposition, and fire effects. As an environmental issue of global concern, the estimates of biomass will directly help to predict the increase of carbon dioxide in the atmosphere. The carbon dioxide flux as a result of land-use change and biomass removal or production are often derived from models that keep an account of the rates of carbon release and uptake. A source of error in these models and/or in other ecosystem process models is the uncertainty in the quantity of vegetation biomass over landscapes as an input parameter.

Circumpolar boreal region are particularly important because it may be the key region for observing the impacts of global climate change. Recent results from Keeling et al.(1996) indicate an increase in the amplitude of the seasonal cycle of atmospheric CO_2, suggesting the lengthening of the growing season in the northern hemisphere, especially in higher latitudes. Motivated by these findings, the BOREAS (boreal ecosystem-atmospheric study) project was designed to improve the status of process models that describe the exchanges of carbon and other trace gases between boreal forest and the atmosphere.

Above ground forest biomass, has been identified as a crucial parameter in many ecosystem process models. However, it's determination has posed a nontrivial problem in both field and remote sensing measurements. Consider the data presented in Figure 1, which show two sets of measurements of biomass for the same homogeneous forest stands which are derived from field measurements. The stands are all within the BOREAS study area. The first set, plotted on the vertical axis, was measured by the Forestry Canada in 1993, and the second set, plotted on the horizontal axis, was measured by the TE-6 group of BOREAS investigators during 1993-1996 field experiments. The 1:1 line is drawn to facilitate the comparison between these measurements. For each stand, represented by solid circles, the standard deviation of each of the measurements is shown. These data were obtained by measuring tree DBH (Diameter at 1.3 m height) and height in certain number of plots (3 for Forestry Canada, and 4 for TE-6) and allometric equations obtained from destructive sampling. The species types varied from stand to stand. The differences between to measurements are as high as about 90 tons/ha. This effect is more pronounced for larger values of biomass, whereas for smaller values, i.e., less than 50

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tons/ha, most measurements are close to the 1:1 line, or at least the error bars reach this line. For larger values of biomass, even the range defined by the error bars does not include this 1:1 line for many stands.
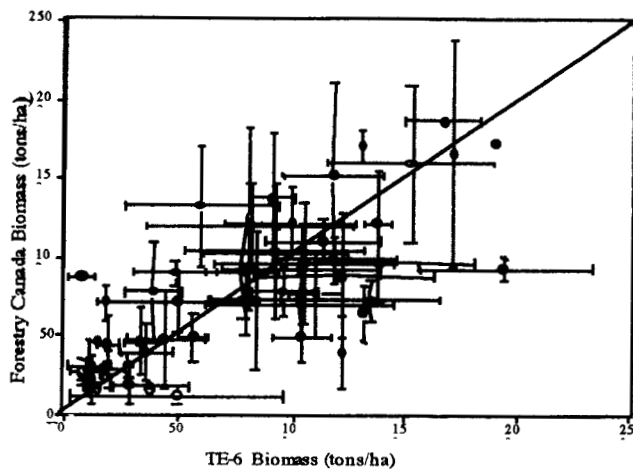

Figure 1. Illustration of discrepancy and error in ground measurement of forest biomass.

The reason for such differences could be the number of plots used in each case, the location of the plots used, spatial variability within each stand, size and weight measurement errors, and human errors. It is also important to note that the biomass estimation through field measurements becomes more difficult as the number of species within the stand increases such as in tropical rainforest.

An alternate method of estimating biomass values has been through remote sensing measurements, in particular those from airborne and spaceborne synthetic aperture radar (SAR). In this category, the dominant methods have been variants of regression analyses, where a regression curve is fitted to a set of backscatter vs. ground-measured biomass values. This curve (usually a line) is then used over other areas and forest stands to obtain biomass for given SAR backscatters. Although simple and practical, this approach is generally not valid if the forest type deviates from those used to obtain the regression curve (Ranson and Sun, 1994; Dobson et al., 1995). Moreover, the accuracy of the regression approach also depends on the number of points used in developing the regression curve which in turn translates into more and accurate field measurements; a difficult process to be avoided.

Another problem with this approach, which results from the foregoing paragraph, is that the biomass values used in regression may not be quite accurate. Moreover, radar backscatter is a strong function of canopy moisture content, i.e., it is not merely the amount of woody biomass, but also the moisture contained in it that contributes to SAR measurements (Saatchi and Moghaddam, 1994). The same forest stand produces very different backscatter depending on whether it is experiencing drought, flood conditions, freezing, or thawing. A valid biomass estimation algorithm must be accompanied by some knowledge of environmental condition and moisture condition of stands. In this paper, such an algorithm is developed and demonstrated.

Approach

The radar backscatter from vegetated surfaces is controlled by two sets of parameters: 1) geometric parameters related to the structure of vegetation and soil, and 2) dielectric parameters related to the moisture content of plants and underlying soil surface. Environmental and physiological conditions, such as availability of water, freezing condition, and leaf out and senescence influence the structural and moisture parameters. The woody biomass of forest canopies are also a function of these parameters. Indeed, the sensitivity of microwave backscatter data to the above ground woody biomass is primarily due to structure and moisture dependent information in the data. Recent studies are primarily focused on developing regression type algorithms for directly estimating vegetation biomass from radar data (Dobson et al., 1995; Ranson et al., 1994,1995; Rignot et al., 1994; Saatchi and Moghaddam, 1994; Saatchi et al., 1995). However, since both structure and moisture parameters exert control over polarization, frequency band, and angular dependence of radar backscatter data, these algorithms become site specific and will not perform well under different environmental conditions.

In this study, we use an alternative approach, by first estimating the forest canopy moisture content and then using conversion factors between dry and wet weight to estimate the above ground woody biomass. The estimation of canopy water content is performed by using a semi-empirical algorithm for boreal type forests

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developed by Saatchi and Moghaddam (1999). The algorithm is based on analytical simplification of a two layer forest backscatter model in order to separate structural and dielectric parameters in forest crown and stem layers. The determination of structural parameters for various forest types will provide a simple algorithm for estimating crown and stem water content and biomass. Figure 2 and 3 shows the relationship between dry and wet biomass and the crown and total biomass from ground measurements.
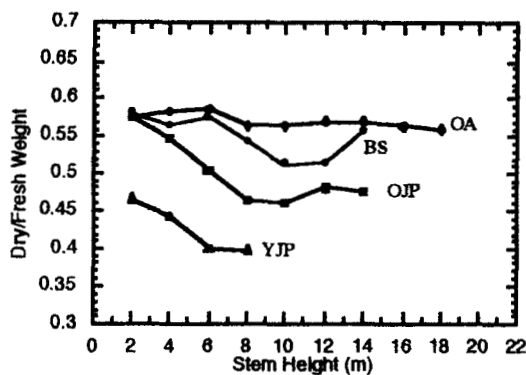

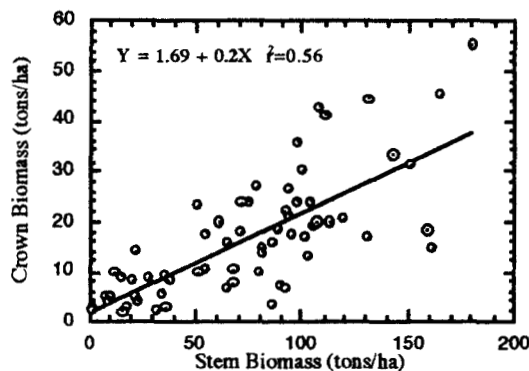Figure 2. Relationship between wet and dry wet of tree stem of four dominant forest stands in the study area.

Figure 3. Relationship between crown and stem biomass for all stands in the study area.

Discussion

Having developed a simplified radar backscatter model for forest canopies, we use the JPL AIRSAR data and the biometric measurements over homogeneous stands dominant in the study area. After using the biometric data in model

equations for each stand, the Levenberg-Marquardt nonlinear least-squares method was used to estimate the structural parameters. The estimation of structural parameters was performed by an iterative method in order to optimized the least square error (less than 1 dB) between SAR measurements and model results. Initial values for each parameter in the iterative procedure were provided by the model simulations using the stand parameters.

Using the structural parameters in equations we readily obtain backscattering equations which are specific to forest types and consist of four unknown parameters, crown and stem water content, soil moisture, and soil surface roughness. To estimate these parameters, we require four independent radar measurements over the forest canopy that are at the same time sensitive to these parameters. To demonstrate the application of the algorithm, we have used the AIRSAR and SIR-C data over the study area. The biomass estimation errors for several current and future spaceborne SAR systems are discussed in the paper.

Acknowledgment

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